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| <b>(54) Title:</b> LIPOSOMAL NUCLEOSIDE ANALOGUES FOR TREATING AIDS<br><br><b>(57) Abstract</b><br><p>A composition is disclosed for use in treating acquired immune deficiency syndrome (AIDS) and related retroviral infections. This composition consists of a phosphorylated nucleoside analogue which is encapsulated in a liposome. 5'-mono-phosphate derivatives of dideoxydinucleoside analogues such as AZT, ddC and ddA are encapsulated in liposomes in a manner which prevents or substantially reduces leakage, resulting in reduced toxic side effects of these drugs and enhanced inhibition of replication of HIV or related viruses present in monocyte/macrophages and other infected cells.</p>                                |           |  |

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LIPOSOMAL NUCLEOSIDE ANALOGUES FOR TREATING AIDSBACKGROUND OF THE INVENTION

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Field of the Invention

The present invention relates generally to the treatment of viral infections with nucleoside analogues. More particularly, the present invention relates to the encapsulation of modified antiviral nucleoside analogues in liposomes to enhance the effectiveness of the analogues when administered to mammals.

This invention was made with Government support under Grant No.: GM-24979 from the National Institutes of Health to the University of California and the Veterans Administration. The Government has certain rights in this invention.

Description of Related Art

The publications and other reference materials referred to herein to describe the background of the invention and to provide additional detail regarding its practice are hereby incorporated by reference. For convenience, the reference materials are numerically referenced and grouped in the bibliography appended at the end of this specification.

There has been a great deal of interest in recent years in the use of nucleoside analogues to treat viral infections. The antiviral nucleoside analogues are designed to inhibit viral functions by preventing the synthesis of new DNA by viral reverse transcriptase during viral replication. Nucleosides are the precursors of DNA or RNA. A nucleoside consists of a pyrimidine or purine base which is linked to a five-carbon sugar.

During DNA synthesis, free nucleoside triphosphates

(nucleosides with three phosphate groups attached) react with the end of a growing DNA chain. The reaction involves the linking of the phosphate group at the 5' position on the incoming nucleoside triphosphate with the hydroxyl group at the 3' position of the sugar ring on the end of the forming DNA chain. The other two phosphate groups are freed during the reaction thereby resulting in the addition of a nucleotide to the DNA chain.

Nucleoside analogues are compounds which mimic the naturally occurring nucleosides sufficiently so that they are able to participate in viral DNA synthesis. However, the antiviral nucleoside analogues have strategically located differences in chemical structure which inhibit the viral enzyme reverse transcriptase or which prevent further DNA synthesis once the analogue has been attached to the growing DNA chain. Azidothymine (AZT), dideoxycytidine, dideoxyadenosine, acyclovir, ribavirin and vidarabine are examples of nucleoside analogues which have been under investigation or have been found effective in disrupting viral DNA or RNA synthesis (1).

Acquired immune deficiency syndrome (AIDS) has been referred to as the first great pandemic of the second half of the 20th century (2). AIDS is caused by the human immune deficiency virus (HIV). There is no effective cure for AIDS at the present time. Dideoxynucleoside analogues such as AZT are the most potent agents currently known, but in a recent human trial, serious toxicity was noted consisting of anemia (24%) and granulocytopenia (16%) (37, 38).

HIV infects cells bearing the CD4 (T4) surface antigen such as CD4 helper lymphocytes as well as CD4 monocytes and macrophages. The infection of CD4 lymphocytes (3-5) results in a cytolytic infection and contributes to the progressive immunodeficiency of HIV

infection (6, 7). More recently, CD4 monocyte/macrophages have been shown to be infected in vitro (8, 9), and in vivo (10-15). Infection of monocyte/macrophages may also contribute to immunodeficiency and to the pathogenesis of HIV induced encephalopathy. In addition, these cells may serve as a reservoir for the virus because HIV replication in monocyte/macrophages appears to be more prolonged and less cytolytic than in lymphocytes. (8, 9, 13).

It would be desirable to provide a means for administering AZT and other dideoxynucleosides in a manner such that the toxic side effects of these drugs are reduced. Further, it would be desirable to provide selective targeting of the dideoxynucleoside to monocyte/macrophages to enhance the efficiency of the drug against viral infection in this group of cells.

In 1965 Alex Bangham and coworkers discovered that dried films of phosphatidylcholine spontaneously formed closed bimolecular leaflet vesicles upon hydration. They used these dispersions to study the capture and diffusion of cations (18). Eventually these structures came to be known as liposomes. Subsequently many potential uses for liposomes were suggested and by 1976 over 60 substances had been reported to become encapsulated in liposomes and a wide variety of uses for liposomes in medicine had been suggested including oral administration of liposomal insulin, selective targeting of liposomes to organs, replacement of missing enzymes and genetic material by liposomal carriers (19).

Many of the above goals have proved elusive. Selective targeting to most organs now seems virtually unattainable because of the tightness of the vascular system; only organs having sinusoids or fenestrated endothelium seem to be possible targets (20, 21). Replacement of deficient enzymes or genetic material has also been difficult because of the relatively rapid

removal of liposomes from the vascular compartment and because fusion of liposomes with cell surface membranes seems not to occur readily (20).

5 As noted in a recent review by Marc Ostro there are many promising uses of liposomes which are nearing the clinical arena (22). For example, liposomal antimonial drugs are several hundred fold more effective than the free drug in treating leishmaniasis as shown independently by Black and Watson (23) and Alving et al (24).  
10 Liposome-entrapped amphotericin B appears to be more effective than the free drug in treating immunosuppressed patients with systemic fungal disease (25, 26). Other uses for liposome encapsulation include restriction of doxorubicin toxicity (27) and diminution of  
15 aminoglycoside toxicity (22).

As previously mentioned it is now thought that macrophages are an important reservoir of HIV infection (28, 29 and 30) and that macrophages are also a primary site of liposome uptake (20, 21). Accordingly, it would  
20 be desirable to utilize liposomes to enhance the effectiveness of antiviral nucleoside analogues in treating AIDS.

Attempts have been made to incorporate nucleoside analogues, such as iododeoxyuridine (IUDR), acyclovir (ACV) and ribavirin into liposomes for treating diseases  
25 other than AIDS (16, 17). However, these attempts have not been entirely satisfactory because these relatively small nucleoside analogues tend to rapidly leak out of the liposome (16, 17) resulting in decreased targeting effectiveness.  
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#### SUMMARY OF THE INVENTION

In accordance with the present invention a new treatment for AIDS is disclosed in which antiviral  
35 nucleoside analogues are trapped within liposomes in a manner which prevents or substantially reduces leakage.

This reduction in leakage provides reduced toxicity and the use of liposomes ensures that a greater amount of the antiviral nucleoside analogue reaches the macrophages to thereby increase the effectiveness of these drugs against the HIV infection present in such cells. The analogue of the nucleoside encapsulated in liposomes further enhances the antiviral effect of the formulation by providing a prephosphorylated antiviral nucleoside, bypassing an enzymatically deficient step in macrophages which would otherwise greatly limit the antiviral activity of the drug itself (43).

The present invention is based on the discovery that leakage of nucleoside analogues from liposomes is greatly reduced if the analogues are converted to phosphate derivatives prior to encapsulation in liposomes. Conversion of the nucleoside analogues to their respective phosphate derivatives is believed not only to prevent leaking of the analogues from the liposomes, but also to increase the effectiveness of the analogues against HIV-infected macrophage cells. As previously mentioned, nucleosides are phosphorylated to the triphosphate form prior to attachment to the growing DNA or RNA chain. Macrophages have been found to have diminished deoxynucleoside kinase activities and a reduced ability to phosphorylate nucleosides. Accordingly, free nucleoside analogues (i.e., non-phosphorylated analogues), such as AZT, ddC or ddA are not particularly effective against HIV present in macrophage cells (43). However, the phosphorylated analogues of the present invention are more effective when presented by the liposomal delivery system because they by-pass the metabolic block caused by the lack of deoxynucleoside kinase activity in macrophages.

The above-discussed features and attendant advantages of the present invention will become apparent as the invention becomes better understood by reference

to the following detailed descriptions.

#### DETAILED DESCRIPTION

5       The present invention basically involves the  
encapsulation of phosphorylated antiviral nucleoside  
analogues within liposomes for use in treating viral  
infections. Although this invention has applications to  
a wide variety of nucleoside analogues which may be used  
to treat various viral infections, the following  
10       description will be in the context of the treatment of  
patients suffering from Acquired Immune Deficiency  
Syndrome (AIDS) and related retroviral infections such  
as AIDS-related complex (ARC), asymptomatic infections  
with HIV-1 and HIV-2 and malignant (lymphoma) or  
15       neurologic (tropical spastic paralysis) complications of  
HTLV-1 or HTLV-2.

Human immunodeficiency virus (HIV, previously  
referred to as HTLV-III/LAV) is the etiologic agent of  
AIDS. As extrapolated from serological surveys, over  
20       1,000,000 Americans have been infected since the virus  
was introduced into the United States in the late  
1970's. By now it is estimated that as many as two  
million people may be infected in the United States.  
Although the majority of these seropositive individuals  
25       are asymptomatic, most, if not all, remain persistently  
infected and thus constitute a pool of potential  
transmitters of infection. A significant fraction of  
these individuals have lymphadenopathy and other  
symptoms, and a smaller proportion, (a few percent per  
30       year) progress to AIDS with its grim prognosis. This  
minority now numbers over 35,000 in the United States  
alone and the number is doubling approximately yearly.

At a cellular level, HIV infects the CD4 (T4)  
helper lymphocyte resulting in the death of these cells.  
35       Depletion of CD4 helper lymphocytes makes the host  
vulnerable to certain well described opportunistic



infections and malignancies. HIV binds to the CD4 receptor of lymphocytes by forming a complex between the 110K viral surface glycoprotein (gp110) and the CD4 antigen (32, 32). Subsequently, the virus is thought to enter the cell by endocytosis as suggested by the finding that productive infection is blocked by  $\text{NH}_4\text{Cl}$  and amantadine pretreatment of the cells. After presumed acid-mediated fusion with the endosome membrane the viral reverse transcriptase and RNA gain access to the cytoplasm and ultimately the viral genetic material gains access to the cell genome. As recently reviewed by Yarchoan and Broder (33) there are at least 9 steps in HIV replication which may provide targets for therapeutic intervention. At present, inhibition of viral reverse transcriptase represents the most promising avenue of antiretroviral therapy.

Recently it has been demonstrated that cells other than the CD4 helper lymphocyte become infected with HIV (28, 29, 30). The virus has been shown to replicate in B cells, promyelocytes and monocytes. It also has been shown that mononuclear phagocytes isolated from brain and lung harbored HIV and normal peripheral blood macrophages produced large quantities of virus. Furthermore, human alveolar macrophages and brain macrophages harbor HIV and the viral cytopathic effects on these cells are much less than that observed in HIV-infected helper T4 lymphocytes. It has been proposed that HIV-infected macrophages and monocytes may serve as a reservoir for virus and that this may be a mechanism for viral persistence and dissemination in the infected host (29, 30).

The present invention utilizes the affinity of macrophages for liposomes as a vehicle for directing liposome encapsulated antiviral nucleoside analogues at macrophages, monocytes and any other infected cells which may take up liposomes. Further, phosphorylation

of the nucleoside analogue prior to encapsulation provides advantages in that: 1) the nucleoside analogue is prevented from leaking out of the liposome; and 2) the metabolic block associated with the inability of macrophages to phosphorylate free nucleosides is overcome. Finally, liposomal encapsulation of the phosphorylated nucleoside is essential to prevent hydrolysis of the phosphate ester by plasma enzymes such as alkaline phosphatase, phosphodiesterases or 5'-nucleotidases.

The nucleoside analogues can be any of the known analogues used for treating AIDS including 3'-azido-3'-deoxythymidine (azidothymidine or AZT), 2',3'-dideoxycytidine (dideoxycytidine or ddC), 2'3'-dideoxyadenosine (dideoxyadenosine or ddA), ribavirin or any other suitable dideoxynucleoside analogue. AZT is a preferred analogue.

The analogue is phosphorylated according to conventional procedures such as the phosphorous oxychloride method of Toorchen and Topal (34). The preferred modified analogue is the 5'-monophosphate. Since AZT and other dideoxynucleosides have only the 5'-hydroxyl, only the 5'-monophosphate is formed during phosphorylation. Alternatively, the nucleoside 5'-monophosphate thioester is also effective. Diphosphate and triphosphate analogues of antiviral nucleosides are also effective, however, these diphosphate or triphosphate analogues tend to be less stable than the monophosphate and may be hydrolyzed gradually back to the monophosphate derivative in aqueous solution.

After phosphorylation, the nucleoside analogue is encapsulated in liposomes. The encapsulation can be carried out according to well known liposome encapsulation procedures such as sonication and extrusion. Suitable conventional methods of encapsulation include but are not limited to those disclosed by Bangham et al

(18), Olson et al (39), Szoka and Papahadjapoulos (40), Mayhew et al (41), Kim et al (42), Mayer et al (36) and Fukunaga et al (35).

5       The liposomes can be made from any of the conventional synthetic or natural phospholipid liposome materials including phospholipids from natural sources such as egg, plant or animal sources such as phosphatidylcholine, phosphatidylethanolamine, phosphatidylglycerol, sphingomyelin, phosphatidylserine or phosphatidylinositol. Synthetic phospholipids may also be  
10       used, such as, but not limited to, dimyristoylphosphatidylcholine, dioleoylphosphatidylcholine, dipalmitoylphosphatidylcholine, distearoylphosphatidylcholine, dilauroylphosphatidylethanolamine, dimyristoylphosphatidylcholine, dipalmitoylphosphatidylcholine,  
15       dioleoylphosphatidylethanolamine and distearoylphosphatidylethanolamine. Other additives such as cholesterol or other sterols, glycolipids, cerebroside, gangliosides, sphingolipids, glucosylceramide, or psychosine can  
20       also be added as is conventionally known. The relative amounts of phospholipid and additives used in the liposomes may be varied if desired. The preferred ranges are from about 80-99 mole percent phospholipid and 1 to 20 mole percent psychosine or other additive.  
25       Cholesterol may be used in amounts ranging from 0 to 50 mole percent. The relative amounts of antiviral nucleoside analogue entrapped in liposomes can be varied with the concentration of entrapped analogue in the liposome aqueous compartment ranging from about 0.001 mM  
30       to about 300 mM.

      The liposome entrapped phosphorylated nucleoside analogue is administered to patients by any of the known procedures utilized for administering liposomes. The liposomes can be administered intravenously, intraperitoneally or intramuscularly as a buffered aqueous  
35       solution. Any pharmaceutically acceptable aqueous

buffer may be utilized so long as it does not destroy the liposome structure or the activity of the encapsulated phosphorylated nucleoside analogue. One suitable aqueous buffer is 150 mM NaCl containing 5mM Na-Phosphate with a pH of about 7.4; other physiological buffered salt solutions may also be used.

The dosage may vary depending upon the extent and severity of the infection. Dosage levels of encapsulated phosphorylated nucleoside analogue should be such that about 0.001 mg/kilogram to 1000 mg/kilogram be administered to the patient on a daily basis.

Examples demonstrating the reduction in leakage of phosphorylated nucleoside analogues from liposomes are as follows:

Initial studies were carried out with [ $^3\text{H}$ ]thymidine and [ $^{14}\text{C}$ ]thymidine-5'-monophosphate,  $28.6 \times 10^6$  DPM of [ $^3\text{H}$ ]thymidine and  $2.510^6$  DPM of [ $^{14}\text{C}$ ]thymidine-5'-monophosphate [ $^{14}\text{C}$ ]TMP in 2.0 ml RPMI buffer was added to a thin film of egg phosphatidylcholine/cholesterol (molar ratio 2:1). After vortexing and swelling for 10 min the suspension was sonicated for 20 min and passed over a Sepharose 4B column as described by Fukunaga et al, (35). Table 1 shows the DPM (and %) of each compound entrapped in multilamellar (MLV) and small unilamellar vesicles (SUV). 1.1% of the [ $^{14}\text{C}$ ]TMP was retained in MLV versus only 0.1% of the [ $^3\text{H}$ ]thymidine. In SUV, 5% of the [ $^{14}\text{C}$ ]TMP was trapped versus only 0.4% of the [ $^3\text{H}$ ]thymidine.

TABLE 1

RETENTION OF RADIOLABELED NUCLEOSIDES IN  
PC/CHOLESTEROL LIPOSOMES

| Sample        | [ <sup>3</sup> H]Thymidine |            |                      | [ <sup>14</sup> C]Thymidine-monophosphate |            |                      |
|---------------|----------------------------|------------|----------------------|---|------------|----------------------|
|               | DPM                        | % of total | % Liposome Retention | DPM                                       | % of total | % Liposome Retention |
| Total Added   | 28,600,000                 | 100.       | -                    | 2,500,000                                 | 100.       | -                    |
| MLV liposomes | 23,740                     | 0.11       | 100                  | 24,100                                    | 1.1        | 100                  |
| Washed MLV    | 4,570                      | 0.02       | 19                   | 20,900                                    | 0.92       | 84                   |
| SUV liposomes | 92,720                     | 0.42       | 100                  | 114,000                                   | 5.0        | 100                  |
| Washed SUV    | 19,510                     | 0.09       | 21                   | 98,500                                    | 4.3        | 86                   |

When the above MLV and SUV were placed in an Amicon ultrafiltration cell and concentrated to a small volume, 86-87% of the [ $^{14}\text{C}$ ]TMP was retained by the liposomes versus only 18-21% for [ $^3\text{H}$ ]thymidine. Overall, only 0.02-.09% of the total [ $^3\text{H}$ ]thymidine was retained versus 0.9-4.3% retained for [ $^{14}\text{C}$ ]TMP. The fact that 50 times more [ $^{14}\text{C}$ ]TMP was ultimately retained in liposomes indicates that [ $^3\text{H}$ ]thymidine cannot be entrapped probably due to rapid diffusion across the lipid bilayer.

Labeled AZT-5'-monophosphate ([ $^3\text{H}$ ]AZT-MP) was prepared according to the phosphorous oxychloride method of Toorchen and Topal (34). Twenty nanomoles of AZT (260 microcuries) was dried under nitrogen. Twenty microliters of trimethylphosphate and 4 microliters of triethylamine were added and the mixture cooled to -10°C. Four microliters of phosphorus oxychloride was added and the mixture was allowed to react at -10°C for 30 minutes. The reaction was stopped by addition of an equal volume of 0.5 M aqueous triethylamine. AZT was converted to AZT-MP in a yield of greater than 90 percent as judged by HPLC on Altex C18 Ultrosphere-ODS column.

The resulting [ $^3\text{H}$ ]AZT-MP was encapsulated in liposomes in the same manner as the [ $^{14}\text{C}$ ]thymidine phosphate and then tested for leakage against free labeled AZT ([ $^3\text{H}$ ]AZT). The results of the tests are shown in Table 2. Only 0.2% of the [ $^3\text{H}$ ]AZT was entrapped in liposomes versus 3.8% of the [ $^3\text{H}$ ]AZT-MP. This indicates that [ $^3\text{H}$ ]AZT, like [ $^3\text{H}$ ]thymidine (Table 1), diffuses out of liposomes as they are being isolated on the Sepharose 4B column. In contrast, [ $^3\text{H}$ ]AZT-MP was entrapped readily; 3.8% of the total was recovered in the liposomal fraction, a 19 fold increase over the percent encapsulation of [ $^3\text{H}$ ]AZT.

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TABLE 2

RETENTION OF [<sup>3</sup>H]AZT AND [<sup>3</sup>H]AZT-5'-MONOPHOSPHATE  
IN PC/CHOLESTEROL LIPOSOMES

| Sample                     | [ <sup>3</sup> H]AZT |            |                      | [ <sup>3</sup> H]AZT-MP |            |                      |
|----------------------------|----------------------|------------|----------------------|-------------------------|------------|----------------------|
|                            | DPM                  | % of total | % Liposome Retention | DPM                     | % of total | % Liposome Retention |
| Total [ <sup>3</sup> H]AZT | 15,320,000           | 100.       | -                    | 13,200,000              | 100.       | -                    |
| Liposome fraction          | 30,390               | 0.20       | 100                  | 497,000                 | 3.8        | 100                  |
| Amicon retentate #1        | 24,485               | 0.16       | 82                   | 493,340                 | 3.7        | 99                   |
| Amicon retentate #2        | 20,473               | 0.13       | 67                   | 493,100                 | 3.7        | 99                   |
| Amicon retentate #3        | 18,617               | 0.12       | 61                   | 490,400                 | 3.7        | 99                   |
| Liposomes, 20hr/4°C        | 13,144               | 0.09       | 43                   | -                       | -          | -                    |

The effect of liposomal AZT monophosphate on HIV replication in MT-2 and U937 cells and human macrophages in culture was tested as follows:

5 A thin film of 27 mg cholesterol and 110 mg egg phosphatidylcholine was prepared by rotary evaporation in vacuo and 1 ml of RPMI medium containing 60 nmol of AZT-MP and 6 uCi [ $^3\text{H}$ ]AZT-MP was added and the mixture was shaken at 20°C. for 20 min followed by 10 cycles of vortexing to produce MLV containing [ $^3\text{H}$ ]AZT-MP.

10 Using a Lipex Extruder (Lipex Biomembranes, Inc., Vancouver, B.C.), small unilamellar vesicles of 100 nanometer diameter (EV 100) were prepared by the method of Mayer et al (36). This procedure is based on extrusion of large multilamellar vesicles through two stacked polycarbonate filters (Nucleopore, Pleasanton, CA).

20 The resulting liposome preparation was applied to a 1x15 cm column of Sepharose 4B and eluted with RPMI buffer. EV 100 liposomes containing [ $^3\text{H}$ ]AZT-MP eluted at the void volume while free [ $^3\text{H}$ ]-drug was collected in the column salt volume. Under these conditions, 14.3% of the [ $^3\text{H}$ ]AZT-MP was trapped. Higher encapsulation efficiencies can be obtained by using more phospholipid per unit volume of buffer and by repeated freezing and thawing (36).

25 EV 100 liposomes containing [ $^3\text{H}$ ]AZT-MP were added in various concentration to MT-2 and U937 cells growing in ELISA plates; to other wells were added AZT-MP and AZT. After 3 days the MT-2 cells ( $6 \times 10^5$  cells/well) were examined for cytopathic effects (CPE) and the results of CPE grading are shown in Table 3.



TABLE 3  
Experiment E725  
EFFECT OF LIPOSOMAL AZT-MP ON  
HIV REPLICATION IN MT-2 CELLS. DAY 7

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|    | rmol<br>drug/well | CPE         |                      |                      |
|----|-------------------|-------------|----------------------|----------------------|
|    |                   | Free<br>AZT | AZT-MP<br>Liposome A | AZT-MP<br>Liposome B |
| 10 | 2                 | 0;0         | 0;0                  | 0;0                  |
|    | 0.2               | 0;0         | 0;0                  | 0;0                  |
|    | 0.02              | 4+4+        | 3+;0                 | 0;0                  |
|    | 0.002             | 4+;4        | 4+;4+                | 0;0                  |
| 15 | 0.002             | 4+;4+       | 4;4+                 | 4+;4+                |

Control, no drug, 4+4+; CPE, cytopathic effects. Liposomes containing [<sup>3</sup>H]AZT-monophosphate were prepared in RPMI medium by the method of Mayer et al (36) and the liposomal AZT-MP encapsulated was determined by the <sup>3</sup>H content of the pooled liposomal peak. Liposomes containing [<sup>3</sup>H]-AZT-MP were added to MT-2 cells infected with HIV in a final volume of 0.200 ml of RPMI medium containing 10% fetal calf serum. Liposome A consisted of 67 mole % egg phosphatidylcholine and 33 mole % cholesterol and Liposome B was made up of 6.6 mole % psychosine and 60 mole % egg phosphatidylcholine and 33.3 mole % cholesterol. Grading of CPD was done as described by Haertle et al (44). In this system 1+ corresponds to 1 to 3 syncytia (giant cells) per well. 2+ corresponds to 3-10 syncytia per well and up to 20% cell death; 3+ corresponds to 10-30 syncytia per well

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and 20-70% drop in cell viability; 4+ corresponds to more than 30 syncytia per well and at least a 70% fall in viable cell count (44).

Similarly,  $6 \times 10^5$  U937 cells growing in ELISA plates were inoculated with HIV. AZT, AZT-MP and liposomal AZT-MP were added to the culture medium as noted above. After 4 days of growth the cell supernatants were removed, diluted 1:100 and assayed for HIV gp24 using the Dupont ELISA System (NEK-041). The results are shown in Table 4.

TABLE 4  
EFFECT OF LIPOSOMAL AZT-MP ON  
HIV REPLICATION IN U937 CELLS

|    |                   | <u>gp24 Antigen, pg/ml</u> |                 |                   |                   |
|----|-------------------|----------------------------|-----------------|-------------------|-------------------|
|    | <u>umol</u>       | <u>nmol</u>                |                 | <u>AZT-MP</u>     | <u>AZT-MP</u>     |
|    | <u>lipid/well</u> | <u>drug/well</u>           | <u>Free AZT</u> | <u>Liposome A</u> | <u>Liposome B</u> |
| 20 | 2.72              | 2.0                        | 1050            | 30                | 30                |
|    | 0.86              | 0.63                       | 1200            | 30                | 30                |
|    | 0.27              | 0.20                       | 3450            | 30                | 30                |
|    | 0.086             | 0.063                      | 2850            | 30                | 30                |
|    | 0.027             | 0.020                      | 3500            | 850               | 30                |
|    | 0.0086            | 0.0063                     | 2800            | 2,100             | 1,600             |
| 25 |                   |                            |                 |                   |                   |

Liposomes containing [ $^3\text{H}$ ]AZT-MP were prepared as in Table 1 and added to U937 cells infected with HIV in 0.200 ml of RPMI containing 10% fetal calf serum. Liposome A consisted of 67 mole % egg phosphatidylcholine and 33 mole % cholesterol and liposome B contained 6.6 mole % psychosine and 60 mole % egg

phosphatidylcholine and 33 mole % cholesterol. Results are mean of 2 replicates.

The effect of liposomal AZT-monophosphate on cultured human macrophages was also determined following the procedures used for MT-2 cells and U937 cells. The results are set forth in Table 5.

TABLE 5  
EFFECT OF LIPOSOMAL AZT-MP ON

HIV REPLICATION IN CULTURED HUMAN MACROPHAGES

gp24 Antigen, pg/ml

|    | <u>umol</u><br><u>lipid/well</u> | <u>nmol</u><br><u>drug/well</u> | <u>Free AZT</u> | <u>AZT-MP</u><br><u>Liposome A</u> | <u>AZT-MP</u><br><u>Liposome B</u> |
|----|----------------------------------|---------------------------------|-----------------|------------------------------------|------------------------------------|
| 15 | -                                | 20.0                            | 2016            | n.d.                               | n.d.                               |
|    | -                                | 6.3                             | 1844            | n.d.                               | n.d.                               |
|    | 2.72                             | 2.0                             | 2524            | 30                                 | 30                                 |
|    | 0.86                             | 0.63                            | 2480            | 30                                 | 30                                 |
| 20 | 0.27                             | 0.20                            | 2116            | 30                                 | 160                                |
|    | 0.086                            | 0.063                           | 2172            | 30                                 | 30                                 |
|    | 0.027                            | 0.020                           | n.d.            | 30                                 | 220                                |
|    | 0.0086                           | 0.006                           | n.d.            | 300                                | 648                                |

n.d. = not determined. Liposome of egg phosphatidylcholine containing [<sup>3</sup>H]AZT-MP in the indicated concentration were prepared as in Table 1 and added to human macrophages. After 3 days in culture the supernatants were assayed for gp24. Liposome A consisted of 67 mole % egg phosphatidylcholine and 33 mole % cholesterol and liposome B contained 6.6 mole % psychosine and 60 mole % egg phosphatidylcholine and 33 mole % cholesterol.

Additional examples of practice are as follows:  
Liposomes of egg phosphatidylcholine/cholesterol (2/1) (100 nanometer diameter) containing [<sup>3</sup>H]AZT-MP were prepared in RPMI medium by the extrusion method of

Mayer et al (36), and the amount of [ $^3\text{H}$ ]AZT-MP encapsulated was determined by  $^3\text{H}$  counts in the voiding peak obtained by gel permeating chromatography using Sepharose 4B. Varying amounts of AZT-MP were added and the effect determined on cells infected with HIV by measuring production of HIV antigen gp24 using the DuPont Elisa assay kit. Two liposome types were prepared -- liposome A and liposome B. Liposome A consisted of 67 mole % egg phosphatidylcholine and 33 mole % cholesterol and liposome B contained 6.6 mole % psychosine and 60 mole % egg phosphatidylcholine and 33 mole % cholesterol. The results of the tests are shown in Table 6.

TABLE 6  
EFFECT OF LIPOSOMAL AZT-MP ON  
HIV REPLICATION IN U937 CELLS

|  |                               | <u>gp24 Antigen, pg/ml</u>      |                 |                                    |                                    |
|--|-------------------------------|---------------------------------|-----------------|------------------------------------|------------------------------------|
|  | <u>umol</u><br><u>PC/well</u> | <u>nmol</u><br><u>drug/well</u> | <u>Free AZT</u> | <u>AZT-MP</u><br><u>Liposome A</u> | <u>AZT-MP</u><br><u>Liposome B</u> |
|  | 4.6                           | 2.0                             | 2,740           | 60                                 | 60                                 |
|  | 0.46                          | 0.2                             | 3,120           | 78                                 | 60                                 |
|  | 0.046                         | 0.02                            | 5,060           | 2,140                              | 1,353                              |
|  | 0.0046                        | 0.002                           | 4,460           | 2,120                              | 13,290                             |
|  | 0.00046                       | 0.0002                          | 10,910          | 13,100                             | 13,980                             |
|  | 0                             | 0                               | (15,420)        | -                                  |                                    |

The liposomal AZT-MP prepared for testing against U937 cells as set forth in Table 6 was also used against HIV-infected human macrophages. The tests were conducted in the same manner as previously described for Table 6 and the results are set forth in Table 7.

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TABLE 7

EFFECT OF LIPOSOMAL AZT-MP ON  
HIV REPLICATION IN HUMAN MACROPHAGES

| 5  | <u>gp24 Antigen, pg/ml</u>    |                                 |                 |                                    |                                    |
|----|-------------------------------|---------------------------------|-----------------|------------------------------------|------------------------------------|
|    | <u>umol</u><br><u>PC/well</u> | <u>nmol</u><br><u>drug/well</u> | <u>Free AZT</u> | <u>AZT-MP</u><br><u>Liposome A</u> | <u>AZT-MP</u><br><u>Liposome B</u> |
| 10 | 4.6                           | 2.0                             | 2,016           | 30                                 | 30                                 |
|    | 0.46                          | 0.2                             | 1,872           | 30                                 | 30                                 |
|    | 0.046                         | 0.02                            | 2,268           | 30                                 | 49                                 |
|    | 0.0046                        | 0.002                           | 2,132           | 2,084                              | 1,632                              |
|    | 0.00046                       | 0.0002                          | 2,248           | 1,732                              | 1,316                              |
| 15 | 0.000046                      | 0.00002                         | 2,800           | 1,448                              | 1,744                              |
|    | 0                             | 0                               | 2,276           | -                                  |                                    |

20            Having thus described exemplary embodiments of the  
present invention, it should be noted by those skilled  
in the art that the within disclosures are exemplary  
only and that various other alternatives, adaptations  
and modifications may be made within the scope of the  
25            present invention. Accordingly, the present invention  
is not limited to the specific embodiments as illu-  
strated herein, but is limited only by the following  
claims.

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What is claimed is:

1. A composition for use in treating acquired immune deficiency syndrome and related retroviral infections comprising a phosphorylated nucleoside analogue which is encapsulated in a liposome and a  
5 pharmaceutically acceptable carrier therefor.

2. A composition according to claim 1 wherein said nucleoside analogue is selected from the group consisting of azidothymidine, dideoxycytidine, dideoxyadenosine and ribavirin.

3. A composition according to claim 2 wherein said phosphorylated nucleoside analogue is the 5'-monophosphate derivative of azidothymidine.

4. A composition according to claim 2 wherein said phosphorylated nucleoside analogue is the 5'-monophosphate derivative of dideoxyadenosine.

5. A composition according to claim 2 wherein said phosphorylated nucleoside analogue is the 5'-monophosphate derivative of dideoxycytidine.

6. A composition according to claim 2 wherein said phosphorylated nucleoside analogue is the 5'-monophosphate derivative of ribavirin.

7. A composition according to claim 1, wherein said liposome is made from at least one of the phospholipids selected from the group consisting of phosphatidylcholine, phosphatidylethanolamine, phosphatidylglycerol, sphingomyelin, phosphatidylserine, phosphatidylinositol, dilauroylphosphatidylcholine, dimyristoylphosphatidylcholine, dioleoylphosphatidylcholine,  
5

10 dipalmitoylphosphatidylcholine, distearoylphosphatidylcholine, dilauroylphosphatidylethanolamine, dimyristoylphosphatidylcholine, dipalmitoylphosphatidylcholine, dioleoylphosphatidylethanolamine and distearoylphosphatidylethanolamine.

5 8. A composition according to claim 7 wherein said liposome further includes additives selected from the group consisting of cholesterol, glycolipids, cerebrosides, gangliosides, sphingolipids, glucopsychosine, and psychosine.

9. A composition according to claim 8 wherein said liposome consists essentially of from about 80-99 mole percent egg phosphatidylcholine and from about 1 to 20 mole percent psychosine.

10. A composition according to claim 9 wherein said phosphorylated nucleoside analogue is the 5'-monophosphate derivative of azidothymidine.

11. A composition according to claim 1 wherein said pharmaceutically acceptable carrier is an aqueous buffer.

5 12. A method for treating acquired immune deficiency syndrome and related retroviral infections in mammals comprising the step of administering to said mammal a pharmaceutically acceptable dose of a composition comprising a phosphorylated nucleoside analogue which is encapsulated in a liposome and a pharmaceutically acceptable carrier therefor.

13. A method according to claim 12 wherein said nucleoside analogue is selected from the group consisting of azidothymidine, dideoxycytidine, dideoxyadenosine

and ribavirin.

14. A method according to claim 13 wherein said phosphorylated nucleoside analogue is the 5'-monophosphate derivative of azidothymidine.

15. A method according to claim 13 wherein said phosphorylated nucleoside analogue is the 5'-monophosphate derivative of dideoxyadenosine.

16. A method according to claim 13 wherein said phosphorylated nucleoside analogue is the 5' derivative of dideoxycytidine.

17. A method according to claim 13 wherein said phosphorylated nucleoside analogue is the 5'-monophosphate derivative of ribavirin.

18. A method according to claim 12 wherein said liposome is made from phospholipids selected from the group consisting of phosphatidylcholine, phosphatidylethanolamine, phosphatidylglycerol, sphingomyelin, phosphatidylserine, phosphatidylinositol, dilauroylphosphatidylcholine, dimyristoylphosphatidylcholine, dioleoylphosphatidylcholine, dipalmitoylphosphatidylcholine, distearoylphosphatidylcholine, dilauroylphosphatidylethanolamine, dimyristoylphosphatidylcholine, dipalmitoylphosphatidylcholine, dioleoylphosphatidylethanolamine and distearoylphosphatidylethanolamine.

19. A method according to claim 18 wherein said liposome further includes an additives selected from the group consisting of cholesterol, glycolipids, cerebroside, gangliosides, sphingolipids, glucopsychosine, and psychosine.

20. A method according to claim 19 wherein said liposome consists essentially of from about 80-99 mole percent egg phosphatidylcholine and from about 1 to 20 mole percent psychosine.

21. A method according to claim 20 wherein said phosphorylated nucleoside analogue is the 5'-mono-phosphate derivative of azidothymidine.

22. A method according to claim 12 wherein said pharmaceutically acceptable carrier is an aqueous buffer.

23. A method according to claim 12 wherein said composition is administered intravenously to said mammal.

24. A composition according to claim 7 wherein the concentration of the phosphorylated nucleoside analogue entrapped within said liposome is between about 0.001 mM to 300 mM.

5 25. A method for preparing a medicament comprising the steps of encapsulating a phosphorylated nucleoside analogue in a liposome to form an encapsulated phosphorylated nucleoside analogue and combining said encapsulated phosphorylated nucleoside analogue with a pharmaceutically acceptable carrier therefor.

5 26. A method for preparing a medicament according to claim 25 wherein said phosphorylated nucleoside analogue is selected from the group consisting of azidothymidine, dideoxycytidine, dideoxyadenosine and ribavirin.

27. A method for preparing a medicament according

to claim 25 wherein said phosphorylated nucleoside  
analogue is prepared by reacting a nucleoside analogue  
with phosphorous oxychloride in the presence of tri-  
methylphosphate and triethylamine.

28. A method for preparing a medicament according  
to claim 26 wherein said phosphorylated nucleoside  
analogue is the 5'-monophosphate derivative of azidothy-  
midine.

29. A method for preparing a medicament according  
to claim 25 wherein said liposome is made from a  
phospholipid selected from the group consisting of  
phosphatidylcholine, phosphatidylethanolamine, phosphatidylglycerol, sphingomyelin, phosphatidylserine,  
phosphatidylinositol, dilauroylphosphatidylcholine,  
dimyristoylphosphatidylcholine, dioleoylphosphatidyl-  
choline, dipalmitoylphosphatidylcholine, distearoyl-  
phosphatidylcholine, dilauroylphosphatidylethanolamine,  
dimyristoylphosphatidylcholine, dipalmitoylphosphatidyl-  
choline, dioleoylphosphatidylethanolamine and dis-  
tearoylphosphatidylethanolamine.

30. A composition according to claim 1 wherein  
said nucleoside analogue is a diphosphate derivative.

31. A composition according to claim 1 wherein  
said nucleoside analogue is a triphosphate derivative.

# INTERNATIONAL SEARCH REPORT

International Application No. PCT/US88/03210

|   |   |   |
|---|---|---|
| <b>I. CLASSIFICATION OF SUBJECT MATTER</b> (if several classification symbols apply, indicate all) <sup>6</sup>   |   |   |
| According to International Patent Classification (IPC) or to both National Classification and IPC   |   |   |
| INT.CL. (4):A61K 9/66, 37/22, 45/05; B01J 13/02.  |   |   |
| U.S.CL. 264/4.1, 4.3; 424/450; 428/402.2; 436/829; 514/885.   |   |   |
| <b>II. FIELDS SEARCHED</b>  |   |   |
| Minimum Documentation Searched <sup>7</sup>   |   |   |
| Classification System   | Classification Symbols  |   |
| U.S.CL.   | 264/4.1, 4.3; 424/450; 428/402.2; 436/829; 514/885.   |   |
| Documentation Searched other than Minimum Documentation<br>to the Extent that such Documents are Included in the Fields Searched <sup>8</sup>   |   |   |
|   |   |   |
| <b>III. DOCUMENTS CONSIDERED TO BE RELEVANT</b> <sup>9</sup>  |   |   |
| Category <sup>*</sup>   | Citation of Document, <sup>11</sup> with indication, where appropriate, of the relevant passages <sup>12</sup>  | Relevant to Claim No. <sup>13</sup>                 |
| Y   | US,A, 4,235,871 PAPAHDJOPOULOS ET AL. PUBLISHED 25 NOVEMBER 1980 SEE EXAMPLES 1, 2 AND 9; AND COL. 6, LINES 31-35.  | 1-31  |
| Y   | BIOCHEMICAL PHARMACOLOGY VOL. 35, NO. 13 PUBLISHED 1986, COONEY ET AL "INITIAL STUDIES ON THE CELLULAR PHARMACOLOGY OF 2', 3'-DIDEOXYCITIDINE; AN INHIBITOR OF HTLV-III ACTIVITY", PAGES 2065-2068.   | 1,2,5,7-9, 11-13,16,18-20, 22-27,29-31              |
| Y   | PROC. NATL. ACAD. SCI. USA, VOL. 83 PUBLISHED NOVEMBER 1986, FURMAN ET AL. "PHOSPHORYLATION OF 3' - AZIDO-3- DEOXYTHYMIDINE AND SELECTIVE INTERACTION OF THE 5' - TRIPHOSPHATE WITH HUMAN IMMUNODEFICIENCY VIRUS REVERSE TRANSCRIPTASE", PAGES 8333-8337. | 1-3,7-14, 18-31                                     |
| Y,P   | US,A, 4,704,357 MITSUYA ET AL. PUBLISHED 03 NOVEMBER 1987, SEE EXAMPLE 3 AND COL. 1, LINE 5-COL. 2, LINE 2.   | 1,2,4,7-9, 11-13,15,18-20, 22-27,29-31              |
| Y   | ANTIMICROBIAL AGENTS AND CHEMOTHERAPY, VOL. 27, NO. 6 PUBLISHED JUNE 1985. KENDE ET AL. "ENHANCED EFFICACY OF LIPOSOME-ENCAPSULATED RIBAVIRIN AGAINST RIET VALLEY FEVER VIRUS INFECTION IN MICE", PAGES 903-907.  | 1,2,6-9,11-13, 17-20,22-27, 29-31                   |
| <div style="display: flex; justify-content: space-between;"> <div style="width: 45%;"> <p><sup>*</sup> Special categories of cited documents: <sup>10</sup></p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> </div> <div style="width: 45%;"> <p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step</p> <p>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.</p> <p>"&amp;" document member of the same patent family</p> </div> </div> |   |   |
| <b>IV. CERTIFICATION</b>  |   |   |
| Date of the Actual Completion of the International Search   |   | Date of Mailing of this International Search Report |
| 01 DECEMBER 1988  |   | 05 JAN 1989   |
| International Searching Authority   |   | Signature of Authorized Officer                     |
| ISA/US  |   | Richard D. Lovering<br>RICHARD D. LOVERING          |



| III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET) |   |  |
|--|---|--|
| Category *   | Citation of Document, with indication, where appropriate, of the relevant passages  | Relevant to Claim No                     |
| Y  | US,A, 4,544,552 FRAEFEL ET AL. PUBLISHED 01 OCTOBER 1985 SEE ABSTRACT; COL. 5, LINES 22-42; AND COL. 9, LINE 31.  | 9,10,20,21                               |
| <del>X</del><br>Y  | NEW ANTI-RETROVIRAL AGENTS AND DELIVERY SYSTEM FOR THE SAME, (U.S.) DEPARTMENT OF HEALTH AND HUMAN SERVICES, WASHINGTON, D.C., PB87-224382 PUBLISHED 10 APRIL 1987, PAGES 1-21. | <del>1-8,11-19,22-31</del><br>9,10,20,21 |
| A  | US,A, 4,291,024 TURCOTTE PUBLISHED 22 SEPTEMBER 1981.   | 1-31                                     |